Exhibit ______

BEFORE THE MINNESOTA OFFICE OF ADMINISTRATIVE HEARINGS
600 North Robert Street
St. Paul, MN 55101

FOR THE MINNESOTA PUBLIC UTILITIES COMMISSION
121 Seventh Place East, Suite 350
St Paul, MN 55101-2147

In the Matter of the Application of Minnesota Power for Authority to Increase Rates for Electric Utility Service in Minnesota	**PUC Docket No. E015/GR-16-664** **OAH Docket No. 5-2500-34078**

DIRECT TESTIMONY OF UDAY VARADARAJAN

On Behalf of

Clean Energy Organizations

May 31, 2017

TABLE OF CONTENTS

I. INTRODUCTION.. 1

II. MINNESOTA POWER'S PROPOSAL TO EXTEND THE ECONOMIC LIVES OF ITS FOUR COAL UNITS AT THE BOSWELL ENERGY CENTER TO 2050. 3

III. CONCLUSION 14

I. INTRODUCTION

Q. Please state your name, employer, and position.

A. My name is Uday Varadarajan. I am a principal in Climate Policy Initiative's Energy Finance Program.

Q. Please summarize your professional experience.

A. My work at Climate Policy Initiative has primarily focused on strategic analysis of clean energy policy, finance, and business structures. In that role, I have provided financial and strategic analysis on matters related to clean energy and utility financing to stakeholders in New York, California, Colorado, Utah, and Missouri. Prior to joining CPI, I was a program examiner in the U.S. White House Office of Management and Budget (OMB) where I oversaw the $2 billion budget for the U.S. Department of Energy's (DOE) energy efficiency and renewable energy programs. I was also responsible for overseeing the assessment of the cost to government – the credit subsidy cost – of the first $8 billion in loans of DOE's Advanced Technology Vehicles Manufacturing Loan Program. Prior to joining OMB, I was a AAAS Science and Technology Policy Fellow, working first as an advisor on carbon sequestration programs to the Under Secretary for Science at DOE and then on detail to the staff of the U.S. House of Representatives, Appropriations Committee. Prior to coming to Washington, I was a postdoctoral fellow in theoretical physics at the University of Texas at Austin, and received my Ph.D. in physics from the University of California at Berkeley, and my undergraduate degree in physics from Princeton University.

Q. Have you previously testified in utility regulatory proceedings?

A. Yes, I have provided written testimony on behalf of Western Resource Advocates to the Colorado Public Utility Commission for proceeding 16A-0231E, focused on revising their depreciation and amortization of operating and retired generating units.

Q. On whose behalf are you testifying?

A. I am testifying on behalf of Minnesota Center for Environmental Advocacy, Fresh Energy, Wind on the Wires, and the Sierra Club (collectively "Clean Energy Organizations" or "CEOs").

Q. What is the purpose of your testimony?

A. On November 2, 2016, Minnesota Power filed an application for authority to increase electric rates, including supporting testimony from Herbert Minke, III regarding Minnesota Power's proposal to extend the economic lives of its four coal units at the Boswell Energy Center to 2050. My testimony responds to this proposal.

Q. Please summarize your findings and conclusions regarding Minnesota Power's proposal to extend the economic lives of its four coal units at the Boswell Energy Center to 2050.

A. Minnesota Power's proposal to extend the remaining depreciation lives of its four coal units at the Boswell Energy Center provides short term savings for current ratepayers at the expense of future ratepayers. There are alternatives mechanisms to better achieve Minnesota Power's stated goals, and the Commission should reject the current proposal and allow Minnesota Power to explore these alternatives.

II. MINNESOTA POWER'S PROPOSAL TO EXTEND THE ECONOMIC LIVES OF ITS FOUR COAL UNITS AT THE BOSWELL ENERGY CENTER TO 2050.

Q. Describe how depreciation of utility assets typically works.

A. Depreciation of a physical asset owned by a regulated utility is a way to allocate the historical investment the utility made in the asset to customers over its expected useful life. Further, annual depreciation expenses reduce the net value of the asset on which a utility earns its regulated rate of return. So, the method and timeline for depreciation determines the profile of utility returns over time from the asset. In other words, depreciation determines how long a utility is allowed to keep earning a return on its investment.

For example, suppose a utility invests $100 million in equipment expected to be in service for 10 years. In this case, one simple way to allocate this investment cost is to equally allocate $10 million as a depreciation expense to customers in each year of its expected life. Under cost of service regulation, a utility is entitled to recover these investment costs in its rates as long as the asset is used and useful. If this is the case, regulators would require that customers compensate the company for this expense, paying $10 million in their rates annually over the 10 year life of the asset. At the end of the 10 year period, the utility would have recovered its $100 million investment, paid for equally by all customers who benefitted from the equipment over its 10 year life.

Depreciation also determines the time profile of allowed returns on a utility's investments. A utility typically earns a regulated return on investments made in assets that are used and useful and allowed in its ratebase. However, the return is calculated based on the historical investment cost net of any costs recovered through customer payments for depreciation expenses. In the example above, suppose the utility is allowed a 10% return on its $100 million asset. Each year, the utility recovers $10 million in costs from customers through payments made to cover asset depreciation expenses. Thus, at the end of the first year, the company had $90 million in unrecovered investment costs - and at the end of the second, $80 million. For the second year, since the utility is only allowed a return on its unrecovered costs, the return the company is allowed is calculated as 10% of its average unrecovered costs over that year (the average of the value at the beginning and end of the second year—$85 million) leading to $8.5 million in allowed returns in year two. For year five, the allowed return drops to $5.5 million—and to $2.5 million for year eight.

In our example, we see that due to relatively rapid depreciation for an asset with just a 10-year life, annual depreciation expenses are substantial—$10 million per year—while annual returns are always lower and drop quickly over time. However, if the asset were long-lived and depreciated over say 40 years, this would no longer be true. In that case, depreciation expenses would stay flat at $2.5 million, but returns would start at $9.7 million in year 2, and decline only to $7.7 million by year 10. Therefore, a longer-lived asset will generally provide greater total returns to the utility over a longer period of time, but at the expense of lower annual revenues. From a customer perspective, a longer-lived asset will cost current customers less overall in the near term, but at the expense of burdening future customers with costs over a longer period of time.

Q. Describe Minnesota Power's proposal to extend the economic lives of its four coal units at the Boswell Energy Center to 2050.

A. At present, the current approved remaining life of Boswell Energy Center (BEC) Units 1 and 2 (BEC 1 & 2) extend to 2024, while BEC Unit 3's approved remaining life extends through 2034 and BEC Unit 4's through 2035, with common facilities extending through 2030. Note that Minnesota Power has announced that it would be retiring BEC 1 & 2 by 2018.

Nevertheless, Minnesota Power proposes treating the BEC as one asset and extending its remaining life for depreciation purposes through 2050, regardless of the physical lives of BEC 3 & 4 and the fact that BEC 1 & 2 will have ceased operating in 2018.

Minnesota Power argues for combining and extending the life of all these units due to:

1) **Ratepayer savings from reduced depreciation expenses**. The extension through 2050 will reduce ratepayer expenses associated with depreciation by $22.7 million annually in the near term, thereby reducing the cost of BEC to current ratepayers.[1]

2) **Recent retrofits to BEC 3 & 4 suggest no technical barrier operation through 2050**. Minnesota Power provides an opinion from a technical consultant, Burns & McDonnell, noting significant experience with operation of coal facilities long past their expected retirements. Burns and McDonnell suggests a lack of any technical barrier to similar continued operation of BEC 3 & 4 past their original expected lives and through 2050 instead.[2]

[1] Direct Testimony of Herbert G. Minke, III at 15 (Nov. 2, 2016).
[2] *Id.* at 18-19.

3) **BEC Units 1 & 2 share critical common infrastructure with Units 3 & 4 not accounted for in common plant**. The Company notes that due to this common infrastructure, retirement of units 1 & 2 will result in the removal from ratebase of historical costs of some assets beyond those currently accounted in common plant that will continue to be used as useful.[3]

4) **Reduced ratepayer exposure to volatile rates associated with uncertain future economic and regulatory changes that may affect BEC**. By reducing the near term cost of BEC to ratepayers, the company claims it will be reducing the exposure of customers to any potential changes in carbon or environmental regulation that might require additional investment (as cost recovery would be extended) or possible early retirement (assuming regulators allow continued cost-recovery through the end of its extended life).[4]

5) **Mitigates the impact caused by early retirement of BEC units 3 & 4 associated with having to pay for replacement assets while also paying for these units.** As the lower depreciation expense reduces the burden on ratepayers associated with all BEC units in the near term, it may soften the blow of a potential future early retirement of an additional unit by creating room in the rates to help pay for new replacement generation while continuing to pay off BEC.

Q. What are your concerns regarding this proposal?

A. We have following concerns with this proposal:

1) **Future ratepayers will continue to pay for BEC 1 & 2—a carbon-intensive asset they will have never used—for 32 years after they are retired**. As we

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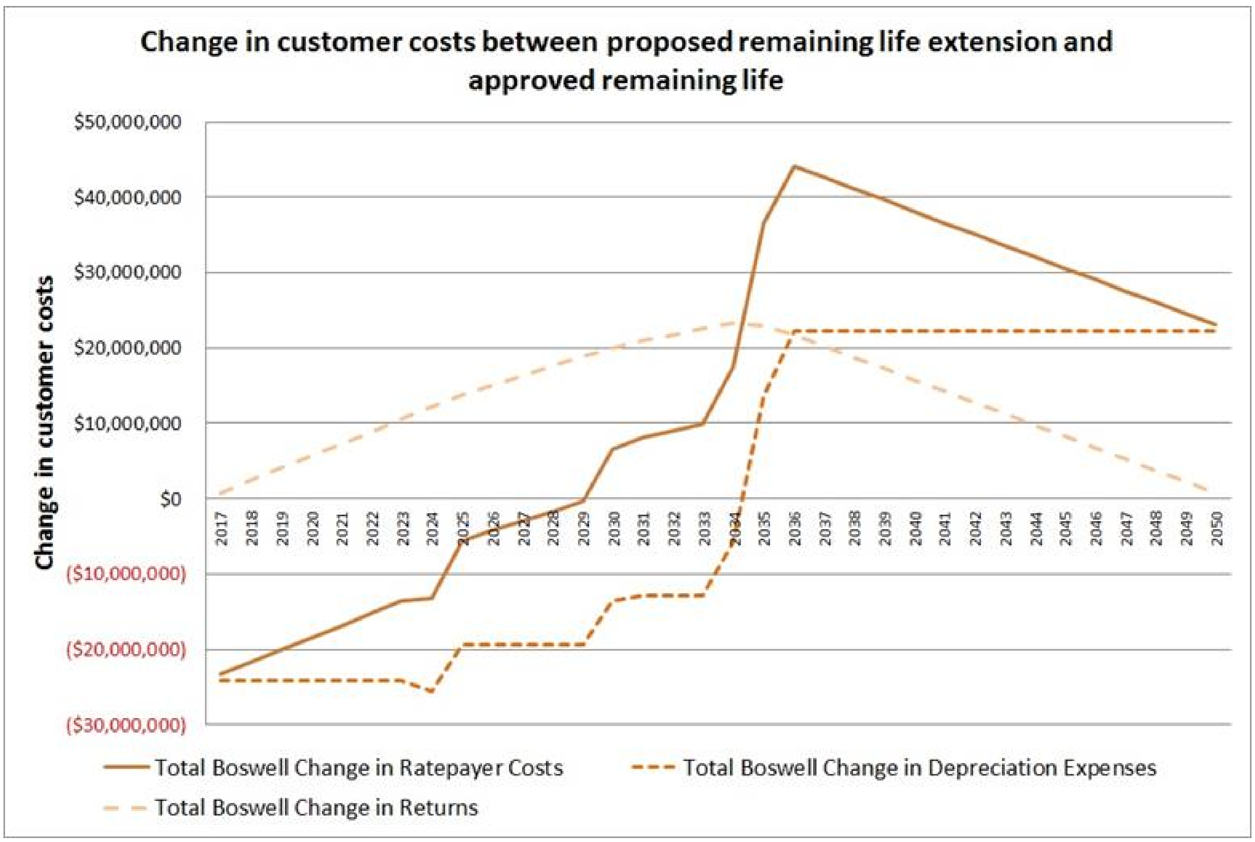
[3] *Id.* at Schedule 9.
[4] *Id.*

noted above, asset depreciation is based on the principle of allocating historical investment costs in an asset over its expected "useful" life. The potential physical life provides one measure of the expected useful life of the asset. Aligning the remaining life for depreciation purposes with this potential physical life would therefore appear to be consistent with this principle. However, Minnesota Power has already announced the retirement of two of its four units by 2018. As a result, the expected useful life of these two units is no longer in doubt and bounded by that retirement date. Further, this announced retirement date is well in advance of the previously approved remaining life of the two units (2024). In a typical depreciation proceeding, the accelerated retirement of the two units would require special consideration to determine an appropriate modified cost recovery approach to both remove the original costs associated with the two retired assets from ratebase and provide cost recovery on unrecovered balances and decommissioning costs to the company. Often, this involves the creation of a short-lived regulatory asset to provide for rapid recovery of unrecovered balances. But Minnesota Power is actually proposing an extension of the remaining life of BEC 1 & 2 for depreciation purposes through 2050. As a result, all unrecovered historical investment costs in these two units—as well as returns to the company on these retired assets—will continue to be paid by ratepayers for an unusually long period of time after the assets have been retired, in violation of the basic principles of depreciation accounting.

2) Taking into account the impact of the Company's proposal on future returns as well as on depreciation expenses, the proposal saves current ratepayers

money at the expense of future ratepayers. My analysis shows that the Company's proposal would increase ratepayer costs through 2050 by a cumulative total of $434 million (undiscounted, nominal dollars) due to higher returns to the company. These costs are unevenly distributed between ratepayers today (who will see net savings of $24 million annually in 2017, declining each year through 2030) and future ratepayers (who will see net costs of $6.5 million in 2030 increasing to nearly $44 million by 2036, then declining slowly to a net cost of $22 million by 2050). See Figure 1 below:

Figure 1: The impact on revenues requirements (and thus customer costs) of Minnesota Power's proposed remaining life extension to 2050 for BEC



3) **Depending on the discount rate used, the proposal results in net present value savings of $54 million (discounting at Minnesota Power's requested**

pre-tax return) or a net cost of $200 million (in current real dollars). The net present value (NPV) of these changes in ratepayers costs depends on the discount rate used. If we use the 11.49% pre-tax utility return as our discount rate, the NPV shows a net savings of $54 million (as the high discount rate minimizes the impact of far off future ratepayer costs). However, one can argue that a lower discount rate is appropriate given the intergenerational impact of this proposed change. Depending on the discount rate used, this results in a net cost to ratepayers of $5 million (using the utility after-tax WACC of 6.74% as the discount rate), $150 million (using the risk free long-term treasury rate of ~3%), or $200 million (in real current dollars, discounting by expected 2% inflation).

4) By boosting future returns from Boswell, this approach creates a financial interest for the Company in continued operation of an increasingly uneconomic, CO_2-intensive asset. This proposal reduces Minnesota Power's revenues from Boswell by decreasing depreciation expenses to current ratepayers, but boosts potential future earnings and earnings growth from the asset. So the proposal boosts the company's exposure to regulatory / market / policy risk associated with being allowed to continue to operate Boswell, but does so while increasing future returns from the asset, aligning the company's interests with continued long-term operation of the plant. As the asset emits an estimated 7 MTons of CO_2 per year, and reports fuel and operating costs totaling $22 per MWh, this aligns the company's financial interests with continued operation of a carbon intensive and uneconomic asset. In contrast to the continued cost of operating BEC, the recent costs of procuring wind energy in Minnesota are less than $20 per MWh. Despite the availability of less-expensive energy, Minnesota Power will be incentivized to continue operating BEC until it's fully depreciated. Specifically, in the near term, the proposal would decrease the Company's revenues from Boswell in the form of lower depreciation expenses, but actually increase its earnings and earnings growth rate from the asset due to greater net asset value in ratebase. In the long-term, as long as the asset remains operational post 2030, the company would see both increased returns and increased overall revenues.

Q. Minnesota Power states that its proposal reduces depreciation expenses in the test year by $22.7 million, which mitigates the rate impact on its customers. Are there alternative ways to mitigate costs to customers for undepreciated utility assets?

A. The simplest approach to addressing this challenge is to leave the approved remaining life unchanged, and thereby leaving depreciation rates unchanged. In this case, customers would not see any increase in rates associated with the early retirement of BEC 1 & 2. The Company would continue to earn returns on its assets as scheduled—except that the early retirement of BEC 1 & 2 would require that the unrecovered plant balances and decommissioning costs net of salvage for the units would need to be transferred to a regulatory asset account. The regulatory asset could be amortized at the same rate at which the units were scheduled to be depreciated, thereby providing continuity and cost certainty to customers and the Company.

However, if any further units of BEC were retired, or if environmental regulations required further investment in the units' pollution control equipment, ratepayers would still be subject to the risk of potential future cost increases. This could result in ratepayers having to pay both the current approved rates for BEC and for additional costs associated with replacement generation or upgrades.

A more constructive approach would be one that addresses this issue and reduces ratepayer costs and risks while aligning Minnesota Power's interests with that of transitioning its assets more rapidly to reflect cleaner, cheaper generation options that could result in cost savings for both current and future ratepayers.

We believe that a tool recently used in Michigan and Florida to finance stranded asset costs could be a promising approach. Since the early 1990s, over twenty states have passed legislation to encourage their public utility commissions to authorize a financial vehicle to refinance the cost of stranded assets known as "ratepayer-backed bond securitization." This financial vehicle can both reduce the cost to ratepayers of early retirement of stranded assets and provide the utility with immediate cost recovery for any remaining net asset balances.

With such appropriate legislative support in place, a public utility commission would execute ratepayer-backed bond securitization by taking the following basic steps:

1) **Set up a company to issue a bond and repay bondholders.** The commission would authorize the formation of a stand-alone company called a special purpose vehicle (SPV) whose sole asset is the rights to a dedicated stream of customer revenues that will be used to pay interest and principal on the bond the SPV issues. The company could be a public benefit corporation set up by the commission (and operated by the utility) as allowed by the authorizing statute or wholly-owned by the utility specifically for this purpose.

2) **Create a dedicated customer revenue stream to pay bondholders.** The commission would set up a dedicated line item on customer's bills whose sole purpose is to pay interest and principal on the bond issued by the SPV. The amount on the line item must be automatically adjusted each month to meet the required interest and principal payments. The rights to the revenues from this line item would be owned by the SPV.

3) **Issue a long-term (15-20 year) bond whose proceeds are used to provide immediate cost recovery to the utility.** The bond's proceeds are used to provide the utility with immediate cost recovery. For example, if this were done in 2018 for the $41 million in expected unrecovered plant balances and expected decommissioning costs net of salvage expected from the early retirement of BEC 1 & 2, a bond of the same size would be issued by the SPV, and the proceeds immediately transferred to the Company. The SPV and revenue line item can be structured to have no impact (or even a positive impact) on the utility's credit rating.

4) **Pay interest and principal on the bond over 15-20 years through dedicated customer revenues.** The dedicated customer revenues are then used by the SPV to pay interest on the bond and repay principal. Since the interest rate can be quite low, and the principal repaid over 15-20 years, the financing costs of securitization can be much lower than paying off a regulatory asset. Specifically, the credit rating agencies (Moody's, S&P) provide detailed criteria for the structuring of the authorizing legislation, the SPV, the revenue line item, and the bond so as to achieve the highest achievable bond credit rating. In today's low-interest-rate environment, such a highly-rated (AAA) bond can result in a 15-20 year bond with a yield below 3%.

As a result of this securitization, instead of the customers paying the company nearly 11.5% in authorized financing costs on a pre-tax basis each year on any outstanding unrecovered balances in assets retired early over an extended period of time, they will instead pay a much lower 3% interest annually over 15-20 years.

For the company, this approach to dealing with the risk of early retirement provides them with the flexibility to recycle their invested capital to take advantage of increasingly attractive future clean energy opportunities. That is, it gives them the option to eliminate underperforming assets when they find it economic to do so without losing their invested capital and with significantly reduced ratepayer impacts, thereby allowing them to potentially redeploy that capital (and more) in more economic alternative assets as the opportunity arises. The value of this option could be more attractive on a risk-adjusted basis in its impact on the long-term growth prospects for the company than the riskier bet they want to make on indefinite operation of Boswell.

Q. Would these alternative mechanisms to mitigate costs to customers for undepreciated utility assets address the concerns you have with respect to Minnesota Power's proposal?

A. I believe that these alternatives could mitigate costs and better align the interests of Minnesota Power with moving towards a cleaner energy future. I intend to provide further analysis demonstrating its potential in possible future retirement scenarios in subsequent submissions. Specifically, I believe that securitization in particular could provide significant savings to both current and future ratepayers and allow the Company to achieve rapid cost recovery for any potential early retirement and reduce its regulatory risk. Further, if the capital recovered is reinvested in wind power with the Production Tax Credit before its expiration, the resulting low cost power could displace more expensive generation, saving customers even more money while further allowing the company to maintain its ratebase and stabilize (or even grow) its earnings. I believe that securitization with capital recycling into new wind by the utility could be a win-win-win for customers, the Company, and the environment.

III. CONCLUSION

Q. What is your recommendation to the Commission with respect to Minnesota Power's proposal to extend the economic lives of its four units at the Boswell Energy Center?

A. This proposal should be rejected as presented. There are alternative mechanisms to achieve Minnesota Power's stated goals without jeopardizing future ratepayers and without the economic and regulatory risk of continuing to run uncompetitive resources.

Q. Does this conclude your testimony?

A. Yes.

QUALIFICATIONS

Uday Varadarajan

Uday is a Principal in CPI Energy Finance's San Francisco office. His work at CPI has primarily focused on strategic analysis of clean energy policy, finance, and business structures. Prior to joining CPI, Uday was a program examiner in the U.S. White House Office of Management and Budget (OMB). At OMB, he oversaw the $2 billion budget for the U.S. Department of Energy's (DOE) energy efficiency and renewable energy programs. He was also responsible for overseeing the assessment of the cost to government – the credit subsidy cost – of the first $8 billion in loans of DOE's Advanced Technology Vehicles Manufacturing Loan Program. Prior to joining OMB, Uday was a AAAS Science and Technology Policy Fellow, working first as an advisor on carbon sequestration programs to the Under Secretary for Science at DOE and then on detail to the staff of the U.S. House of Representatives, Appropriations Committee. Prior to coming to Washington, Uday was a postdoctoral fellow in theoretical physics at the University of Texas at Austin. He received his Ph.D. in physics from the University of California at Berkeley, and his undergraduate degree in physics from Princeton University.

EXPERIENCE

Climate Policy Initiative **2010 – Present**
Principal *San Francisco*

My work at CPI has primarily focused on strategic analysis of clean energy policy, finance, and business structures.

- Heading team executing a $500k grant from Rockefeller foundation to develop new low-cost investment vehicles focused on efficiently financing renewable energy assets tailored to investor needs.
- Headed team that executed $720k in grants and contracts from three foundations and two partners to perform financial analysis to assess options to make the transition from coal to renewables in Colorado, the PacifiCorp service territory, and Missouri work for all stakeholders.
- Detailed financial and economic modeling over two years for NYSERDA on various topics related to the NY Large-Scale Renewables proceeding, including quantitative economic and financial analysis of the potential reduction in financing costs that could be achieved by alternative renewable policy and procurement mechanisms for NYSERDA Report Number 15-12 "Large-Scale Renewable Energy Development in New York: Options and Assessment," presentation of those results at the NYSERDA LSR technical conference in July of 2015, analysis of wind hedge value, and assessment of NYISO electricity market price forecasts for a proposed NY Green Bank loan.
- Headed team executing a $75k contract for Swedish Growth Analysis on potential shifts in policies, market structures, and business models needed to cost-effectively drive a transition to a low-carbon electricity grid dominated by variable generation sources.
- Performed financial modeling of the comparative potential impact of several legislative proposals to reform the U.S. tax code on the cost of wind, solar, and gas generation for the Bipartisan Policy Center.
- Project and portfolio financial analysis of the potential for new business models – Master Limited Partnerships, YieldCos – to reduce to cost of capital for renewable energy in the U.S. and E.U.

- Financial analysis resulting in a proposal to U.S. congressional staff of an alternative to the U.S. use of tax credits that would reduce their cost to government by 40% while providing the same level of benefit to wind developers and investors.
- In-depth financial and policy case studies of several U.S. and E.U. renewable project financings (Ivanpah CSP, Milford Wind, and Greater Sandhill PV in the U.S., Villanueva Wind, Rovigo PV, and Anholt Offshore Wind in the E.U.), resulting in quantitative assessments of the impact of alternative policy structures on financing costs.

Executive Office of the President, Office of Management and Budget (OMB) 2008 – 2010
Program Examiner in the Energy Branch Washington, DC

I was responsible for reviewing the Department of Energy's Office of Energy Efficiency and Renewable Energy's (EERE) budget submission to OMB and providing my recommendation to OMB's leadership regarding their funding for inclusion in the President's annual budget submission to Congress. I was also the examiner responsible for oversight of the Advanced Technology Vehicles Manufacturing Loan Program (ATVM).

- As the first examiner for the ATVM program, I worked with DOE to develop and approve the credit subsidy model for the program, as required by the Federal Credit Reform Act. This model is being used to estimate the cost to the government of providing up to $25 billion in Federal direct loans to auto manufacturers. Worked with DOE to review and approve the subsidy cost for $8.4 billion in loans to Nissan, Tesla, Ford, and Fisker. Received an OMB division-level award for my work on this model and the program.
- Supported OMB review and assessment of cost to government of several loan guarantees made by the U.S. DOE Title XVII Loan Program, including loans to Solyndra, First Wind, Shepherd's Flat Wind, Abengoa's Solana CSP, and Ivanpah CSP.
- Worked with the Presidential Transition Team, providing analysis to inform their submissions to Congress regarding renewable energy and energy efficiency items for inclusion in the American Re-investment and Recovery Act
- Subsequent to the passage of the Recovery Act, worked with EERE to review and approve their detailed project and program plans for nearly $16.8 billion in renewable energy and energy efficiency spending.
- Worked with other examiners to use EIA data to model the impact of Federal tax incentives and loan programs on the cost of electricity from various sources to inform budget decision-making.
- Reviewed the FY 2010 and FY 2011 EERE budget submissions, and worked with DOE to review and approve their budget justifications to Congress. Continue to work with EERE to track program performance and execution in support of the Administration's energy policy objectives.

AAAS Science and Technology Policy Fellowship 2006-2008
Fellow Washington, DC

2008: I was sent on detail from the Department of Energy (DOE) to the Majority Staff of the Committee on Appropriations, House of Representatives, Subcommittee on Energy and Water Development, where I supported development of the appropriations bill to fund the Department of Energy.

- I provided the Subcommittee with input, analysis, and advice in support of crafting the Committee's FY 2009 Energy and Water Appropriations bill and committee report, which fund the Department of Energy and other agencies. My primary responsibility was to address issues relevant to the DOE Office of Science, and serve as support on issues relevant to the DOE Fossil Energy, Energy Efficiency and Renewable Energy, and Energy Transmission and Distribution programs.

- Built an Access database, forms, and reports to allow quick & easy access to the Congressional requests made to the Subcommittee by the 435 members of the House of Representatives regarding the bill and used the database to analyze these requests and support decision-making.

2006-2008: I advised the Under Secretary on science issues relevant to the applied energy technology programs, particularly the fossil energy program and the scientific issues surrounding carbon dioxide capture and sequestration.

- Played a leading role in a review of the DOE R&D portfolio which resulted in the identification of six key opportunities for accelerating innovation through better coordination of R&D budgets in the basic and applied science and technology programs across the department. The President's FY 2009 budget funded requests across the department identified by our analysis as relevant to these six opportunities and presented integrated budgets for these areas for the first time.
- Led the creation of an action plan to implement an integrated basic and applied science program in support of the geological storage of carbon dioxide emissions from coal power plants. Worked with science and technology program staff to begin the implementation of this plan
- Leading the creation of a new web page for the Office of High Energy Physics at DOE, as well as a public outreach web portal for the field of high energy physics.
- Was the lead support staff in editing, producing, and rolling-out the Report of the Interagency Task Force on High Energy Density Physics, outlining a Federal strategy to support this emerging field of science with promising applications to fusion energy.

String Theory and Theoretical High Energy Physics **2001-2006**
Graduate Researcher and Post-Doctoral Fellow *Berkeley, CA and Austin, TX*

I was a postdoctoral fellow in the Weinberg Theory Group at UT Austin from 2003-2006, and before that, a graduate researcher in the Physics Division of Lawrence Berkeley Labs from 2001-2003. I worked on a range of topics within String Theory, a candidate "theory of everything". For instance, with Prof. Horava and collaborators, we suggested that a novel feature of string theory (holography) may exclude the possibility of time travel (for a popular account, see The New Scientist, Sep 20th, 2003, p.28).

Experimental Condensed Matter Physics - Carbon Nanotubes **1997-1999**
Graduate Researcher *Berkeley, CA*

I was a graduate researcher in the Material Science Division of LBNL, where I synthesized carbon nanotubes (long, thin tubes - just nanometers in diameter- each made up of a single, one atom thick layer of graphite). I also worked to characterize the materials at the National Center for Electron Microscopy and Berkeley Microlab using TEM, SEM, and AFM techniques. I further explored the electronic properties of tangles of tubes as well as individual tubes using nanodevices we fabricated using electron-beam lithography.

Other Physics Research (Princeton Undergraduate) **1993-1996**
Undergraduate Researcher *Princeton, NJ*

- **Biophysics:** Senior Thesis w/ C. Callan - a model for DNA stretching. (1995-1996)
- **High Energy Experiment:** Simulation of a HERA-B pretrigger. (Summer 1995)
- **Plasma Physics:** DOE Fellowship at PPPL - numerical Poisson Solver. (Summer 1994)
- **Nuclear Physics:** Simulation of the Borexino Neutrino Detector. (1993-1994)

EDUCATION

University of California at Berkeley **2003**
Ph.D., Physics *Berkeley, CA*

- Advisor: Bruno Zumino
- Dissertation: "Geometry, Topology and String Theory"

University of California at Berkeley **1998**
M.A., Physics *Berkeley, CA*

- Advisor: Alex Zettl
- Focus: Synthesis and Characterization of Carbon Nanotubes

Princeton University **1996**
A.B. (Magna Cum Laude), Physics *Princeton, NJ*

- Certificates in Mathematical Physics and Engineering Physics (1996)
- Thesis Advisor: Curtis G. Callan
- Senior Thesis: "The Role of Solitons in the Overstretching of B-DNA"
- Allen G. Shenstone Prize in Physics, Princeton University (1996)
- Kusaka Memorial Prize in Physics, Princeton University (1995)